Fermi National Accelerator Laboratory

FERMILAB-Conf-99/247-E
D0

The Status of the D0 Silicon Tracker Upgrade Project

Frank Lehner

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

September 1999

Published Proceedings of the *8th International Workshop on Vertex Detectors,*
Texel, The Netherlands, June 20-25, 1999

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

The Status of the DØ Silicon Tracker Upgrade Project ⋆

Frank Lehner [1]

Fermilab, P.O. Box 500, Batavia, IL 60510, U.S.A.

Abstract

The current status of the silicon tracker for the DØ upgrade project for Run II at the Tevatron is presented. After reviewing the design considerations the status of delivery and testing of the different silicon sensors is presented. The ladder production and assembly process is also discussed.

1 Introduction

Run II of the upgraded Tevatron collider is supposed to start in the summer of the year 2000. With a higher peak Luminosity of 10^{32} cm^{-2}s^{-1} and a reduced bunch crossing time of 396 ns - in a later stage 132 ns - Run II will deliver in the first 2 years of its operation a twenty-fold increase in integrated luminosity compared to the previous run. To optimize its physics capability for the future run, the DØ detector is presently being upgraded [1]. The muon system trigger and front-end electronics will be replaced to obtain improved triggering rejection power. Scintillator layers in the central muon system are added to the existing muon chamber and a replacement of the forward muon system with mini-drift tubes is in progress. The calorimeter electronics will be upgraded to match the reduced bunch crossing time and increased luminosity. New central and forward preshower detectors have been added to improve electron and photon identification. A 2 Tesla super-conducting solenoid, having a 1066 mm inside diameter and a coil length of 2556 mm, has been installed to provide a magnetic axial field. Furthermore the central tracking system will be replaced entirely by a scintillating fiber tracker, which consists of eight concentric barrels of scintillating fiber doublet layers read out with visible

⋆ Talk presented on behalf of the DØ Collaboration at the 8th International Workshop on Vertex Detectors, June 20-25 1999, Texel, The Netherlands.

[1] representing the DØ Collaboration

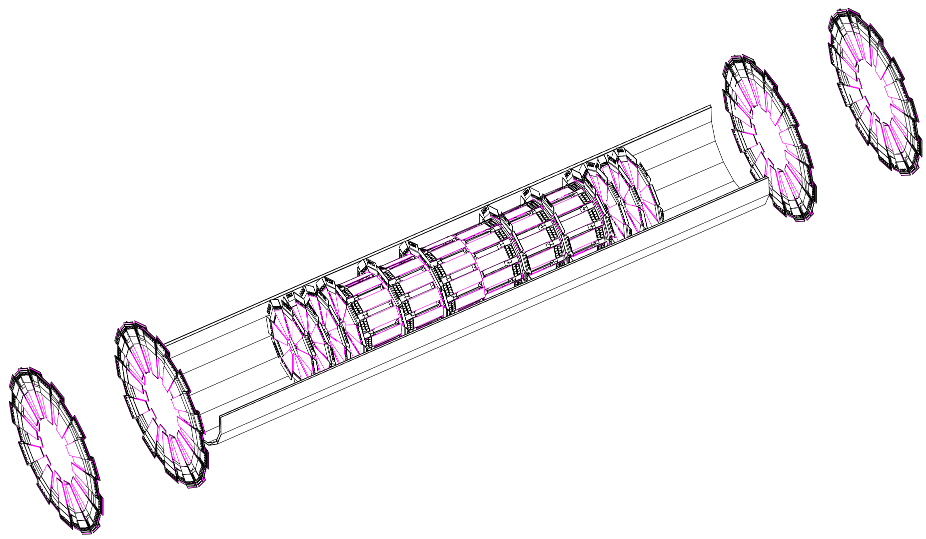

Fig. 1. The barrel/disk design of the DØ silicon tracker.

light photon counters (VLPC). The detector upgrade is completed with the installation of a new silicon vertex detector around the beam pipe.

2 Overview of the silicon tracker design

The silicon tracker [2] consists of six barrel modules with silicon sensors parallel to the beamline, as well as twelve "F-disks" and four sets of "H-disks" with silicon normal to the beamline (Figure 1). The main motivation for choosing such a design is the extended interaction region in the beam direction with $\sigma \approx$ 25 cm. The silicon tracker should be able to allow for a three-dimensional track reconstruction with z-vertex and transverse impact parameter resolutions of better than 30 μm. A good acceptance for high p_T-tracks, mainly from top-decays, and silicon based tracking and vertexing in the forward regions for $2 < |\eta| < 3$ is also required. The detector and its on-board mounted electronics have to cope with the expected Run II environment and have to be radiation hard up to 3 MRad. These considerations led to a design with six 12.4 cm long barrels with interspersed F-disks and external large area H-disks for a better forward momentum resolution. The barrel modules and the F-disks are supported by a double-walled carbon-fiber/epoxy half cylinder, which aids in maintaining precise alignment. The half cylinder locates the silicon tracker relative to the scintillating fiber tracker and serves as support for cabling and cooling channels. The 762 mm long barrel region provides in four concentric layers with radii ranging from 2.7 cm to 9.4 cm tracking up to $|\eta| \approx 2$ for tracks originating from the center of the interaction region. Since the momentum resolution for tracks at rapidities of $|\eta| > 2$ is seriously degraded in the central barrel, large area H-disks are added to extend and improve the tracking range

Table 1
Parameters of the DØ silicon tracker:

D0	**Barrels**	**F-Disks**	**H-Disks**
Layers/planes	4	12	4
Channels	387120	258000	147456
Modules	432	144	192
Readout Length	12.4 cm	7.5 cm	14.6 cm
Inner Radius	2.7 cm	2.6 cm	9.5
Outer Radius	9.4	10.5	26 cm

for rapidities of up to $|\eta| \approx 3$.

Each of the 4 main layers of the barrel consists of two sublayers with an radial offset of 6 mm, which provides adequate clearance for the cooling channel. This design also allows for a routing of the cables between the sublayers, hence reducing the inter-barrel spacing. In addition there is substantial overlap between the detectors in the sublayers and among the main layers. The staggered arrangement will on the one side simplify the alignment procedure, but on the other side introduces a small phi-dependence in the impact parameter resolution. Layers 2 and 4 of the barrels are double sided silicon sensors with a stereo angle of 2°. Layers 1 and 3 of the four inner barrels have 90° stereo detectors, whereas both layers of the two outer barrels consist of single sided detectors.

Table 1 lists some of the parameters of the silicon tracker. There are 792,576 readout channels in total. Hence the DØ silicon tracker is intermediate in size between previous generation of micro vertex detectors and those being designed for the LHC.

3 Silicon detectors

In the following the various detector types, which are used for the DØ silicon tracker, are described in more detail:

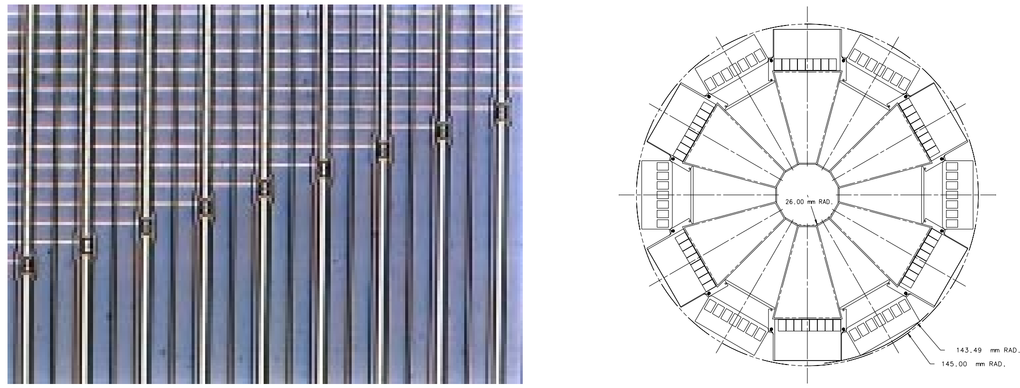

Fig. 2. Left: close-up of strips of a double sided, double metal 90°-detector. Right: fully assembled F-disk plane.

3.1 Single sided detectors

For the layers 1 and 3 of the two outer barrels a total of 144 single sided detectors are needed. They are AC-coupled and have a strip pitch of 50 μm. All detectors have been received and have been tested with a yield of 75%. They show depletion voltages of typically 30 V and have more than 99.5% good strips. The signal to noise ratio of a single sided ladder has been determined to be S/N=21 with a mean equivalent noise charge of 1200 e^- [3]. The radiation hardness has been tested at the 8 GeV booster test facility at Fermilab. It was found that the design of the single sided detectors with one single guard ring structure is robust enough to operate these detectors up to 220 V without any sign of breakdown.

3.2 Double sided detectors: 2°*-stereo*

The small angle stereo detectors or 2°-detectors are AC-coupled, double sided detectors with a pitch of 50 μm and 62.5 μm on the p-side and n-side respectively. For the assembly of layers 2 and 4 of all six barrels a total of 432 such detectors is needed. Presently we have roughly 50% usable detectors in hand. After some major delivery problems in the fall and winter of last year, our vendor Micron Semiconductor has significantly increased the detector production rate since February this year. Based on the current delivery rates we expect to receive all detectors by December 1999.

3.3 Double sided detectors: 90°*-stereo*

The large angle stereo or 90°-detectors are AC-coupled, double sided, double metal detectors processed in a 6”-wafer technology. For layers 1 and 3 of the inner 4 barrels 144 such detectors are needed. The pitch on the p-side is 50 μm, whereas the n-side uses a pitch of 153 μm. In addition there is a multiplexing factor of 2 as two implant strips are linked together by the double metal layer to form one readout channel. Figure 2 left shows a close-up of the double metal side of the detectors. The implant strips running vertically, the horizontal metal traces and the vias are visible. After receiving several prototypes, the final design of these detectors with an individual p-stop geometry on the n-side has been recently approved. As of now the vendor has delivered the first 20 production detectors, which have been tested at Fermilab. Approximately 80-90% of the production type detectors fulfill our specifications. It is further expected that all 90°-detectors will be delivered to Fermilab by the end of this year.

3.4 F-disks

To assemble the 12 planes of F-disk detectors we need 144 trapezoidal shaped sensors. Figure 2 shows one plane of an assembled F-disk detector. The F-wedges are AC-coupled, double sided detectors with an angle of $\pm 15°$ with respect to the vertical direction. The pitch is 50 μm and 62.5 μm on the p- and n-side respectively and constant over the wedge, whereas the strip length varies across the face of the detectors. The F-disk sensors are under production but have had a rather low output rate and an unacceptable yield in the past. Therefore an alternative vendor (Eurisys Measures) has been identified at the end of last year, and the full order has been split between the two companies. We are expecting to receive the last shipment of F-wedges by February next year.

3.5 H-disks

In total 384 H-wedges are needed to assemble the 4 planes of the large external area disks, which will greatly improve the track momentum resolution for rapidities of up to $|\eta| \approx 3$. The H-wedges are AC-coupled, single sided detectors with a constant pitch of 40 μm. The strips are running at an angle of 7.5° and two wedges are glued back to back to achieve an effective stereo angle of 15°. The production of these wedges is done at ELMA, a company near Moscow. Almost 80% of all wedges have been already arrived at Fermilab and we expect to receive the remaining sensors by the end of August.

3.6 Detector testing

The quality control for the barrel detectors and for the F-disks is directly done at the vendor. Two automatic probe stations and measurement equipment have been set up at the company and are operated by two DØ technicians. The standard tests done on all devices include leakage current measurements, depletion voltage determination, measurements of bias- and interstrip resistances, coupling capacitor measurements and a search for shorted capacitors. As an acceptance criterion, we allow for a maximum number of 2% of bad strips on each side.

A major problem for some earlier batches of detectors was a very low and unacceptable resistance between neighboring strips on the p-side. The interstrip resistance was found to be in the order of only a few kΩ and smaller than the bias resistors on the devices. The most probable reason for this problem has been identified as a contamination in a purge gas which was used during the annealing process. Currently all our received and accepted detectors show high interstrip resistances of several GΩ and are in full agreement with the specifications. Another problem occurred on the first prototype batches of 90°-detectors. The number of broken vias in the double metal layer was very high and outside our specifications. However, a thicker metalization cured this problem and all the recently received production type detectors do not indicate any sign of a fragile second metal layer.

4 SVX II Chip and Readout System

The silicon detectors are readout using the SVX II chip [4], which is fabricated in a radiation hard 1.2 μm CMOS technology. The average power dissipation for the 128 channel device is 5mW per channel. The chip features a preamplifier, a 32 cell deep analog pipeline and an 8 bit Wilkinson type ADC with sparsified readout. The ADC ramp, pedestal, preamplifier bandwidth and polarity can be set by downloading the relevant parameters. The design of the chip requires it to operate on each edge of a 53 MHz clock. The internal chip noise has been determined to be 350 $e + 50\ e$/pF with a bandwidth setting of 200 ns. All SVX II chips, which are needed for the silicon tracker, have been fabricated and tested with a yield of roughly 70%. It has been found that all features of the chip are working successfully and reliably [5].

The SVX II chips and other readout electronic components are mounted on a kapton based flex circuit (high density interconnect, or HDI), which - in the case of double sided silicon - is wrapped around one silicon edge to serve both ladder surfaces. The HDIs provide for electrical connections at the ladder edges

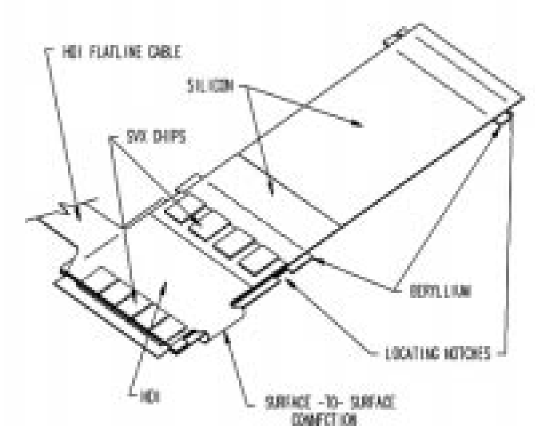

Fig. 3. View of a silicon ladder.

and help to reduce the gaps between the barrels to a minimum. The flexible long tail of the HDI allows the routing of the cable to the outer side of the barrel region. The four layers of the barrel and the disk/barrel geometry of the tracker require 9 different types of HDIs carrying 3, 6, 8 or 9 chips and various length. Currently all HDIs for the 3- & 9-chip ladders have arrived and the other HDI types are under production at various companies.

Further connections to the outside world are done by 6 ft. long low mass cables connecting the ends of the HDI tails to a transition card module. At the moment only a prototype version of the low mass cable exists, but all basic design questions have been addressed. The transition card is mounted on the central calorimeter cryostat and routes the signals to an interface card by using a 30 ft. long high mass cable. The signals are then sent to a sequencer board which provides an optical link to the VME readout buffer modules in the electronics trailer of the DØ detector.

To test the whole readout and DAQ chain a system test is presently being performed. It consists of the readout of the equivalent of 20,000 SVX II channels through the sequencer and VME interface. It also includes an interface to the third Level of the DØ Trigger/DAQ frame. A sustained readout of 12 Mbyte/s is obtained. The readout error rate, which has been achieved so far, is less than 10^{-14} and several cabling and impedance matching problems have been solved. The system test will soon be extended to a real '10%-test' of the silicon tracker by reading out one complete assembled and equipped disk/barrel module and by taking cosmic data.

5 Mechanical Design and Assembly

The considerations of minimal mass, precise alignment and adequate thermal performance of the silicon detectors in the barrels and disks have led to a de-

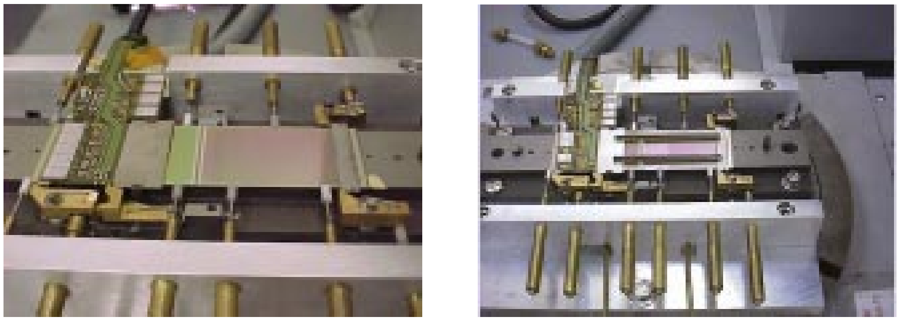

Fig. 4. Different stages of the production of a silicon ladder.

sign of the basic detector unit with 400 μm thick beryllium substrates glued to the silicon. The ladder design of a double sided silicon detector is shown in figure 3. The 3- & 9-chip ladders consist of two 300 μm thick silicon sensors each with a dimension of 6 cm x 2.1 cm, which are positioned back to back and are electrically connected with wirebonds. The positioning of the ladder in the barrel is achieved by precisely machined notches in the beryllium substrates, which fit into posts at the bulkhead surface. To fix the ladder, a pin arrangement is used, which also allows for the removal of the ladder if necessary. The silicon ladders are aligned in the barrel with the help of coordinate measuring machines. An accuracy in the positioning of the ladders of $\pm$10 μm in the transverse direction and $\pm$50 μm in the radial direction is anticipated.

The beryllium substrates support the ladder and act as heat sinks. The HDIs are laminated onto these beryllium substrates to maintain the flatness of the kapton and to provide a thermal path from the heat sources on the HDI to the cooled bulkhead. Thermally and electrically conductive epoxies are used in the pin and post arrangement to allow for adequate heat transfer. In addition to the beryllium pieces two rails, each consisting of a carbon/boron fiber, Rohacell foam, carbon/boron fiber sandwich are glued to the silicon ladder parallel to the long side to ensure a stable relative position of the silicon sensors. The rail material has been chosen to match the thermal expansion coefficient of silicon. The silicon tracker is expected to operate at a temperature of 5-10°C. The cooling system uses a mixture of deionized water/glycol and the chillers are designed to work down to temperatures as low as -10°C.

In February this year we have successfully started with the production of 3- & 9-chip ladders. Recently, the fabrication of H-wedges has begun and in addition first F-wedge prototypes have been built. The 6-chip ladder production, using the 90°-detectors, is expected to start soon. Furthermore, the first production type ladders have been already inserted into the barrel bulkheads to start the assembly process of the first barrel/disk module, which will later be used for the '10%' system readout test.

Figure 4 shows two stages in the 9-chip ladder production process. The left figure shows two silicon sensors, that have been aligned back to back and the beryllium piece is glued to the silicon. The beryllium piece itself is laminated to the HDI carrying 5 chips for the p-side and 4 chips for the n-side. Spring arms in the fixture push the beryllium piece against the fixture posts , to mimic the posts of the bulkhead. In the right picture of figure 4 two longitudinal rails have been glued on the silicon to provide for a better mechanical stiffness of the ladder. In the next step the ladder is flipped and the HDI is wrapped around the silicon edge and glued to the other side. All the ladders and wedges are produced in the Silicon Detector Facility at Fermilab and the complete making of the DØ silicon tracker remains a big production task with more than 1000 ladders/wedges to build and more than 1,5 Million of wires to bond.

Each produced ladder is carefully checked on test stands. We have set up several test stands, including one laser test station, to perform quality checks on the ladders. Beside functional tests of the chip and HDI component readout, the tests include a search for unbonded channels or broken wirebonds as well as laser scans to find shorted channels, which have not been detected before.

6 Summary and conclusions

Much progress has been made over the last 1/2 year towards the building of the DØ silicon tracker. The ladder and wedge production has successfully started for 3 out of the 5 detector types. The remaining F-wedge and 6-chip ladder fabrication is expected to begin in summer. Most of the parts which are needed for the fabrication process are in hand. We also have commissioned several test stands to perform quality controls on the produced ladders. A big progress occurred in the detector delivery rates, which could be increased by the silicon vendor over the last half year. In addition the help of two DØ technicians, locally at the company and responsible for detector testing tasks, has had a significant impact on the production yields and output rates. With the exception of the F-wedges, we are expecting to receive all our silicon detectors by end of this year. The anticipated delivery rates from the additional vendor, which has been found for the F-wedges, will be complimentary to the rather slow rate of the original vendor, and the split in the F-disk order will ensure that all F-wedges will arrive by February next year.

There is still a lot of work necessary to turn the electronic readout test from its present form into a real '10%' system test of a complete barrel/disk being able to readout cosmic data. Also the assembly of the first barrel/disk module remains a challenge. Nevertheless we are expecting to finish the construction of the DØ silicon tracker early next year in order to be ready for the Run II data in summer 2000.

References

[1] The DØ Collaboration, *The DØ Upgrade Project* (Fermilab-Pub 96-357, 1996)

[2] The DØ Collaboration, *The DØ Silicon Tracker Technical Design Report* (DØ note 2169, Fermilab, 1994)

[3] M. Roco for the DØ Collaboration, *The Silicon Microstrip Tracker for the DØ Upgrade* (to be published in proceedings of 6th International Conference on Advanced Technology and Particle Physics, Villa Olma, Italy, 5-9 Oct 1998)

[4] R. Yarema et al. *A Beginners Guide to the SVX II Chip* (Fermilab-TM-1892, 1994)

[5] R. Lipton for the DØ Collaboration, *The DØ Silicon Tracker* (Nucl. Instr. and Meth. A 418, 1998)